# T962 LAR TPC PRELIMINARY ODH ANALYSIS CALCULATIONS

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## (1.0) Introduction

This document presents calculations used for the T962 LAR TPC preliminary Minos Hall ODH analysis. A number of approximations and estimates were made in these calculations that will have to be revised for the final safety documentation. The intent here was to have calculations accurate enough to show that it is feasible for the Minos Hall to be made ODH Class 0.

## (2.0) General Information

### (2.1) Basic Equipment Failure Rates

FESHM 5064.TA pages 4-5, Table 2, NRC Equipment Failure Rate Estimates

```
Pfdew  =  1e-6**(1/hr)      (probability of dewar rupture)
```

FESHM 5064.TA page 3, Table 1, Fermilab Equipment Failure Rate Estimates

```
Pfp  =  1e-9**(1/hr)      (probability of pipe section failure)
Pfv  =  1e-8**(1/hr)      (probability of valve external leak)
Pfr  =  1e-5**(1/hr)      (probability of premature opening of relief valve)
Pfw  =  3e-9**(1/hr)      (probability of weld failure)
Pfg  =  3e-7**(1/hr)      (probability of gasket failure)
Pfms  =  3e-4      (probability of motor failure to start on demand)
Pmoterfail  =  1e-5**(1/hr)      (probability of running motor failure)
Ppowerout  =  1e-4**(1/hr)      (probability of a power outage)
Pdieselfail  =  3e-2      (probability of diesel plant not starting on demand)
```

### (2.2) Fan Failure Rates

#### Option 1, Fan failure

For option 1 there would be two mixing fans. A description of the mixing system is in section 7.0. These two 1000 cfm fans are in parallel. Only one of the fans has to be running to satisfy the system requirements. These fans will be in generator backup power and have a UPS permitting operation of one of the fans for at least several hours. The motor size would be small, most likely 1/4 horsepower or less so a UPS will be feasible. Oxygen monitors will cause mixing fans to automatically start. Assume the UPS fails to operate once every thousand demands.

```
PfUPS  =  1e-3      (probability of failure of UPS per demand)
```

One way for the mixing system to fail is a simultaneously three events must occur: an electric power outage, the diesel generator fails to run and the UPS fails. Another way is if both mixing fans fail to start at the same time. The probability of failure for the option one mixing system is:

```
Pffan1  =  PfUPS*Pdieselfail*1**hr*Ppowerout+Pfms*Pfms
Pffan1  =  0.93e-7
```

**Option 2 Fan Failure**

For option 2 there would be one mixing fauna in diesel generator backup power. The fan will not operate if there is a power outage and the diesel generator does not start or if the fan motor fails to start. The option 2 mixing fan is also used in option 3.

```
Pffan2  =  Pdieselfail*1**hr*Ppowerout+Pfms
Pffan2  =  0.303e-3
```

**Option 3 Fan Failure**

Option 3 has the same mixing fan as option 2 and in addition uses the existing surface fan, EF-4 which pulls 4000-6000 scfm of air from the ceiling of the Minos Hall through a 350 ft duct to the surface. It is on generator backup power. It has the same probability of failure as the option 2 mixing fan.

```
Pfef4  =  Pdieselfail*1**hr*Ppowerout+Pfms
Pfef4  =  0.303e-3
```

## (2.3) Fluid Properties

From Airco Industrial Gases Data Handbook (AGG 1077C), the following data was acquired. Listed are the densities at standard conditions (70 F and 1 ATM) of helium. nitrogen and air. Also there is the density of Liquid nitrogen at 1 ATM and the conversion of gallons of liquid nitrogen to cubic feet of nitrogen gas at standard conditions.

```
RhoStdAir  =  0.07493**(lb/ft^3)      (density of air at standard conditions)
RhoStdAr  =  0.1034**(lb/ft^3)      (density of argon at standard conditions)
CpAr  =  0.1244**(BTU/(lb*R))      (specific heat of argon gas)
CpAir  =  0.2406**(BTU/(lb*R))      (specific heat of air)
RhoLAr  =  1.3936**(lb/L)      (density of liquid argon at 1 atm)
```

density of water

```
rhoH2O  =  62.4**(lb/ft^3)
```

density and viscosity of saturated vapor argon at 1 atm. AIRCO Industrial Gases Data Book

```
RhoArVap  =  0.35976**(lb/ft^3)      (argon vapor density)
MuArVap  =  72.4e-6**(gm/(cm*s))      (argon vapor viscosity)
```

## (2.4) Ventilation Rates

Option 1 and option 2 mixing fan ventilation rate.

```
Qmixfan  =  1000**(ft^3/min)
```

fan EF-4, loacated on the surface drawing air from the ceiling of Minos Hall.

```
Qef4  =  4000**(ft^3/min)
```

## (2.5) Minos Hall Dimensions

From Drawing No. 6-7-4 C-57

```
Hmh  =  32**ft      (height of main hall)
Lmh  =  150**ft      (length of main hall)
Wmh  =  35**ft+10**in      (width of main hall)
Wmh  =  Convert(ToFt)Wmh
Wmh  =  35.8333333332**ft
Hmat  =  21**ft+6**in      (height Minos Access Tunnel)
Hmat  =  Convert(ToFt)Hmat
Hmat  =  21.5**ft
```

The Minos Access Tunnel length is approximate.

```
Lmat  =  200**ft      (length of Minos access tunnel)
Wmat  =  21**ft+6**in      (width of Minos access tunnel)
Wmat  =  Convert(ToFt)Wmat
Wmat  =  21.5**ft
```

Volume of Minos Hall and Minos access tunnel.

```
Vol  =  Hmh*Lmh*Wmh+Hmat*Lmat*Wmat
Vol  =  0.26445e6**(ft^3)
```

Volume of lower 7 ft of Minos Hall and Minos access tunnel.

```
Vol7  =  7**ft*(Lmh*Wmh+Lmat*Wmat)
Vol7  =  0.67725e5**(ft^3)
```

Volume of lower 3 ft of Minos Hall and Minos access tunnel.

```
Vol3  =  3**ft*(Lmh*Wmh+Lmat*Wmat)
Vol3  =  0.29025e5**(ft^3)
```

Volume of lower 1 ft of Minos Hall and Minos access tunnel.

```
Vol1  =  1.0**ft*(Lmh*Wmh+Lmat*Wmat)
Vol1  =  9674.9999999999**(ft^3)
```

## (2.6) Cryogenic System Data

The argon cryogenic system has not been be fully designed and hence conservative estimates must be made of the size of the system. The total argon inventory in the Minos Hall is important for the ODH analysis. The full, the liquid argon dewar can hold 500L of liquid argon. At the end of filling operations, there could still be a partial 160 L portable dewar left in the Minos Hall. Assume a full 160 L dewar connected to a full 500L stationary dewar.

```
TVLAr  =  660**L      (total volume of liquid argon)
TMAr  =  TVLAr*RhoLAr      (total mass of argon)
TMAr  =  919.776**lb
TQAr  =  TMAr/RhoStdAr      (total stanard cubic feeet of argon)
TQAr  =  8895.3191489364**(ft^3)
```

The number of different types of components is required for an ODH analysis. The total number of argon valves, including relief valves but not including vacuum valves is.

```
NumArV  =  20      (number of argon valves)
```

FESHM 5064 lists failure rates of piping as per section of pipe. Generally pipes come in 20 ft sections. Assume 100 ft of pipe and tubing.

```
SecArPipe  =  5.      (sections of argon piping)
```

The number of relief valves does not include vacuum reliefs.

```
NumArRV  =  5      (number of argon relief valves)
```

Number of welds on the argon piping system. This does not include welds on the dewar or vacuum jackets.

```
NumArWelds  =  100      (number of welds on argon piping)
```

There will be no traditional piping gaskets on the system. But there will be a number of connections with metal to metal seals. The probability of failure for gaskets, listed in FESHM 5064, for these connections. This number does not include the top flange.

```
NumArGasket  =  5      (number of joints with seals)
```

# (3.0) Preliminary Calculations

## (3.1) Venting into the intake duct of Ef-4.

The highest vent rate into the vent header From section 2.3 of T962 LAR TPC RELIEF DEVICE SIZING CALCULATIONS the maximum mass flow rate from the fire condition is

```
Wfire  =  0.2136430106e3**(lb/hr)
```

Treat the flow in the duct as a mixture of argon and air.

```
War  =  Wfire      (mass flow rate of argon in the mixture)
War  =  0.2136430106e3**(lb/hr)
RRar  =  War/RhoStdAr      (volumetric flow rate of argon at standard conditions)
RRar  =  0.2066179986e4**(ft^3/hr)
RRar  =  Convert(ToMin)RRar
RRar  =  0.0344363331e3**(ft^3/min)
```

The total flow rate of the mixture is the rating of the fan EF-4.

```
Qmix  =  4000**(ft^3/min)
```

Everything in the that is not argon is air.

```
Qair  =  Qmix-RRar
Qair  =  3965.5636668923**(ft^3/min)
Wair  =  Qair*RhoStdAir
Wair  =  297.1396855602**(lb/min)
Wair  =  Convert(ToHr)Wair
Wair  =  0.178283812e5**(lb/hr)
```

Find the temperature of the mixture. Assume the argon entering the duct is cold at the saturation temperature of the dewar.

```
Tar  =  180**R      (temperature of the argon)
Tair  =  530**R      (air enters at 70 F)
Tmix  =  (Tair*Wair*CpAir+Tar*War*CpAr)/(Wair*CpAir+War*CpAr)
Tmix  =  527.8448026035**R
```

The temperature of the mixture is negligbly different than the temperature of the incoming Minos Hall air. Find the mixture density

```
rhomix  =  (War+Wair)/(Wair/RhoStdAir+War/RhoStdAr)      (mixture density)
rhomix  =  0.0751751006**(lb/ft^3)
rhomix/RhoStdAir  =  1.0032710609      (ratio of mixture density to air density)
```

There is little change in the density. The conclusion is that the pressure drop in the duct and the EF-4 fan volumetric flow rate is little changed by the presense of the argon. Therefore if the fan EF-4 is running it is able to remove argon vented into it from the Minos Hall, if any argon valve opens, venting into the argon vent line then the Fatality rate in the Minos Hall is 0 for that situation.

## (3.2) Complete Mixing in Minos Hall and Minos Access Tunnel

Assume the entire inventory of argon is released and mixed. Only pure air is displaced to make room for the argon. Subtract total standard cubic feet of argon TQAr (section 2.5)from the combined volume of the Minos Hall and Minos access tunnel, Vol (section 2.4).

```
Qair  =  Vol-TQAr      (standard cubic feet of air)
Qair  =  0.2555546808e6**(ft^3)
ocr  =  0.21*Qair/Vol      (oxygen concentration)
ocr  =  0.2029362184
FatalityFactor(ocr)  =  0.0**fatalities      (fatality factor)
```

The above calculation assumed all of the argon is spilled and stays in the hall and access tunnel, there is complete mixing and no fresh air enters. The resulting oxygen concentration is over 18% and the fatality rate is 0.

## (3.3) Complete Mixing in the Bottom 7 ft of the Minos Hall and Minos Access Tunnel

Assume the entire inventory of argon is released and mixed. Only pure air is displaced to make room for the argon. Subtract total standard cubic feet of argon TQAr (section 2.5)from the volume of bottom 6 ft of the Minos Hall and Minos access tunnel, Vol6 (section 2.4).

```
Qair  =  Vol7-TQAr      (standard cubic feet of air)
Qair  =  0.5882968085e5**(ft^3)
ocr  =  0.21*Qair/Vol7      (oxygen concentration)
ocr  =  0.182417615
FatalityFactor(ocr)  =  0.0**fatalities      (fatality factor)
```

The above calculation assumed all of the argon is spilled and stays in the hall and access tunnel, there is complete mixing and no fresh air enters. The resulting oxygen concentration is over 18% and the fatality rate is 0. Complete mixing in the entire cavern is not required.

## (3.3)B Complete Mixing in the Bottom 3 ft of the Minos Hall and Minos Access Tunnel

Assume the entire inventory of argon is released and mixed. Only pure air is displaced to make room for the argon. Subtract total standard cubic feet of argon TQAr (section 2.5)from the volume of bottom 6 ft of the Minos Hall and Minos access tunnel, Vol6 (section 2.4).

```
Qair  =  Vol3-TQAr      (standard cubic feet of air)
Qair  =  0.2012968085e5**(ft^3)
ocr  =  0.21*Qair/Vol3      (oxygen concentration)
ocr  =  0.1456411017
FatalityFactor(ocr)  =  0.00003775**fatalities      (fatality factor)
```

The above calculation assumed all of the argon is spilled and stays in the hall and access tunnel, there is complete mixing and no fresh air enters. The resulting oxygen concentration is over 18% and the fatality rate is 0. Complete mixing in the entire cavern is not required.

## (3.4) Complete Mixing in the Bottom 1 ft of the Minos Hall and Minos Access Tunnel

Assume the entire inventory of argon is released and mixed. Only pure air is displaced to make room for the argon. Subtract total standard cubic feet of argon TQAr (section 2.5) from the volume of bottom 1 ft of the Minos Hall and Minos access tunnel, Vol1 (section 2.4).

```
Qair  =  Vol1-TQAr      (standard cubic feet of air)
Qair  =  779.6808510634**(ft^3)
ocr  =  0.21*Qair/Vol1      (oxygen concentration)
ocr  =  0.0169233053
FatalityFactor(ocr)  =  1.0**fatalities      (fatality factor)
```

The above calculation showed that if all of the argon is spilled and stays in the hall and access tunnel,and there is complete mixing the resulting oxygen concentration is less than 2% and the fatality rate is 0.

## (3.5) Dewar Heater

```
RRheater  =  (500**L*RhoLAr/RhoStdAr)/24**hr
RRheater  =  280.7865892972**(ft^3/hr)
RRheater  =  Convert(ToMin)RRheater
RRheater  =  4.6797764882**(ft^3/min)
```

## (3.6) Release Rate From Severed 1/4 in Tube

Assume there is a failure on the piping system.

```
od  =  0.250**in       (tube outside diamtere)
wall  =  0.035**in       (wallthickness)
id  =  od-2*wall       (internal diameter)
id  =  0.1799999999**in
a  =  id^2*Pi()/4       (flow area)
a  =  0.0254469005**(in^2)
```

Because of the high inlet pressure, there will be sonic flow. Calculate the flow rate using formulas from Anderson Greenwood catalog 2-S80-89 for series 80 relief valves. Assume a flow coefficient K = 0.62 for a sharp edged orifice. Fermilab atmospheric pressure is about 14.3 psia.

```
M  =  40       (molecular weight)
T  =  520**R       (inlet temperature)
Z  =  1       (compressibility factor)
A  =  0.0254469005**(in^2)       (orifice area)
```

Conditions

```
C  =  377       (argon gas constant)
Kd  =  0.62       (coeffifient of discharge)
Pin  =  1.1*30**psig+14.7**psia       (inlet absolute pressure)
Pin  =  47.6999999999**psia
```

Mass flow rate of argon

```
W  =  (C*Kd*Pin*A*(M/(T*Z))^0.5)**(lb*R^0.5/(hr*psia*in^2))
W  =  78.6891101501**(lb/hr)
```

Argon release rate in standard cubic feet per minute.

```
RRpipe  =  W/RhoStdAr       (argon release rate)
RRpipe  =  761.0165391696**(ft^3/hr)
RRpipe  =  Convert(ToMin)RRpipe
RRpipe  =  12.6836089861**(ft^3/min)
```

## (3.7) Release Rate From Dewar Vacuum Jacket Flange

42 in flange

```
flangeid  =  43**in
flangeod  =  47**in
gap  =  0.010**in
wd  =  Pi()*(flangeid+flangeod)/2       (average width of the flow path)
wd  =  141.3716694115**in
a  =  wd*gap
a  =  1.4137166941**(in^2)
Le  =  (flangeod-flangeid)/2
Le  =  2.**in
dp  =  1**psi
```

fluid properties

```
rho  =  0.35976**(lb/ft^3)       (density)
mu  =  72.4e-6**(gm/(cm*s))       (viscosity)
```

Hydraulic diameter is 4 times the flow area divided by the perimeter of the flow path.

```
dh  =  4*a/(2*wd)
```

```
dh  =  0.02**in
```

Assume f

```
f  =  0.035      (assume a friction factor)
```

input K factors

```
Kin  =  0.5
Kout  =  1.0
Kl  =  f*Le/dh
Kl  =  3.5
Ktotal  =  Kin+Kl+Kout      (total K factor)
Ktotal  =  5.
```

Calculate Velocity

```
v  =  ((dp*2*gc)/(Ktotal*rho))^0.5      (velocity)
v  =  5.9810314645**((ft^2.*psi^0.5)/(lbf^0.5*s))
v  =  Convert({{psi<-1*lbf/in^2},ToFt})v
v  =  71.7723776032**(ft/s)
Re  =  dh*v*rho/mu      (Reynolds number)
Re  =  0.0071328261e6**((in*lb*cm)/(ft^2*gm))
Re  =  Convert({ToFt,ToSec,ToLb})Re
Re  =  0.0088456797e6
epsilon  =  0.00015**ft      (pipe roughness)
f  =  FrictionFactor3(Re,epsilon,id)      (confirm assumed friction factor)
f  =  0.0437825043
```

outputs

```
w  =  a*v*rho      (mass flow)
w  =  36.5033392278**((in^2*lb)/(s*ft^2))
w  =  Convert(ToFt)w
w  =  0.2534954096**(lb/s)
RRvflange  =  w/RhoStdAr      (volumetric flow at standard conditions)
RRvflange  =  2.4515997068**(ft^3/s)
RRvflange  =  Convert(ToMin)RRvflange
RRvflange  =  147.0959829958**(ft^3/min)
```

## (3.8) Release Rate From Dewar Top Flange.

Use the dimensions of the raised face of a 24 in, 150 #, weld neck flange.

```
flangeid  =  23.25**in
flangeod  =  27.25**in
gap  =  0.010**in
wd  =  Pi()*(flangeid+flangeod)/2      (average width of the flow path)
wd  =  79.3252145031**in
a  =  wd*gap
a  =  0.793252145**(in^2)
Le  =  (flangeod-flangeid)/2
Le  =  2.**in
dp  =  30**psi
```

Fluid properties

```
rho  =  0.35976**(lb/ft^3)      (density)
mu  =  72.4e-6**(gm/(cm*s))      (viscosity)
```

Hydraulic diameter is 4 times the flow area divided by the perimeter of the flow path.

```
dh  =  4*a/(2*wd)
dh  =  0.02**in
```

Assume f

```
f  =  0.035      (assume a friction factor)
```

input K factors

```
Kin  =  0.5
Kout  =  1.0
Kl  =  3.5
Ktotal  =  Kin+Kl+Kout      (total K factor)
Ktotal  =  5.
```

Calculate Velocity

```
v  =  ((dp*2*gc)/(Ktotal*rho))^0.5      (velocity)
v  =  32.7594585034**((ft^2.*psi^0.5)/(lbf^0.5*s))
v  =  Convert({{psi<-1*lbf/in^2},ToFt})v
v  =  393.1135021988**(ft/s)
Re  =  dh*v*rho/mu      (Reynolds number)
Re  =  0.0390680976e6**((in*lb*cm)/(ft^2*gm))
Re  =  Convert({ToFt,ToSec,ToLb})Re
Re  =  0.0484497834e6
epsilon  =  0.00015**ft      (pipe roughness)
f  =  FrictionFactor3(Re,epsilon,id)      (confirm assumed friction factor)
f  =  0.0391367814
```

outputs

```
w  =  a*v*rho      (mass flow)
w  =  112.1868852386**((in^2*lb)/(s*ft^2))
w  =  Convert(ToFt)w
w  =  0.7790755869**(lb/s)
RRtflange  =  w/RhoStdAr      (volumetric flow at standard conditions)
RRtflange  =  7.5345801445**(ft^3/s)
RRtflange  =  Convert(ToMin)RRtflange
RRtflange  =  452.0748104827**(ft^3/min)
```

The value of RRflange number. It is probably very conservative because it assume the oring seal completely disappears. In reality, if the oring (or metal seal) broke and leaked, most of the oring would stay in place and restrict the flow. Next, assume the even if the initial release rate we this large, the dewar pressure would quickly drop off and the both dewar pressure and release rate will decrease. A sustained argon release rate is limited by the thermal load on the dewar. The heat load will be the heat load from the vacuum jacket and two heaters in the dewar used to remove liquid and control pressure.

## (3.9) Release Rate from Dewar Vacuum Releif

Section 4.2 of the document T962 LAR TPC RELIEF DEVICE SIZING CALCULATIONS

```
RRvjr  =  20.36**(ft^3/min)
```

## (3.10) Dewar Inner Vessel Release Rate Due To Loss of Vacuum.

The release rate from dewar main relief when there is a loss of vacuum. This value is for when the vacuum space is spoiled with air. The vacuum space could be spoiled with argon as well, but due to argon lower thermal conductivity it is a less severe case. Value was calculated in the Section 3.3 of the document T962 LAR TPC RELIEF DEVICE SIZING CACULATIONS

```
RRdewr  =  7.3481377705**(ft^3/min)
```

////

# (4.0) Probability of Events That Cause Large Argon Releases

## (4.1) (Case 1) Dewar Inner Vessel Failure

This dewar is unusual in that ithe inner vessel is not entirely welded; it has a large internal flange with a metal seal. The probability of a failure of the inner vessel will be then be the normal dewar failure rate used at Fermilab plus a gasket failure rate to account for the possibility of the flange seal leaking.

```
Pr1  =  Pfdew+Pfg      (case probability)
Pr1  =  0.13e-5**(hr^(-1))
```

## (4.2) (Case 2) Dewar Vacuum Vessel Failure

The vacuum vessel can fail through one of four ways: failure of the welded vessel, failure of the flanged seal, and failure of the vacuum valves. Use the FESHM chapter dewar failure probability for a vacuum jacket failure and a gasket failure probability for the flanged seal. The vacuum jacket will have two valves, a parallel plate relief valve and a CVI brand relief valve that will also serve as a pumpout port. These valves can fail by an external leak or by premature opening.

```
Pr2  =  Pfdew+Pfg+2*Pfr+2*Pfv      (case probability)
Pr2  =  0.2132e-4**(hr^(-1))
```

## (4.3) Case 3, Probability of Failed Argon Piping

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
Pr3  =  Pfp*SecArPipe+Pfv*NumArV+Pfw*NumArWelds+Pfg*NumArGasket      (case 3 probab
Pr3  =  0.2005e-5**(hr^(-1))
```

## (4.4) Case 4, LAr Dewar Top Flange Leak

Treat the top flanged joint as a gasket joint.

```
Pr4  =  3e-7**(1/hr)      (case 4 probability)
```

## (4.5) Case 5, Premature Open Relief Valves

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
Pr5  =  3e-7**(1/hr)      (case 5 probability)
```

### (4.6) Case 6, Major Operational Problems

If the argon vent system discharges into the Minos Hall, then operational problems will cause an argon release into the Minos Hall. Estimate the probability of an operational event which causes an argon release big enough to for an oxygen deficiency hazard to be once every 6 months.

```
Pr6  =  (1/(24*6*31))**(1/hr)      (case 6 probability)
Pr6  =  0.0002240143**(1/hr)
```

## (5.0) Argon Release Rates

### (5.1) (Case 1) Dewar Internal Vessel Failure

This failure will cause a loss of vacuum and a high heat load for the dewar. The dewar relief valve, the vacuum space relief valve and the dewar vacuum flange will all vent helium as a consequence. Release rate RRflange is from dewar vacuum flange, section 3.7. The release rate from the vacuum jacketed relief RRvj is discussed in sec 3.9. The release rate RRv is from the dewar main relief; see section 3.10.

```
RR1  =  RRvflange+RRvjr+RRdewr      (case 1 release rate)
RR1  =  174.8041207663**(ft^3/min)
RR1sv  =  RRvflange      (case 1 release rate with surface vent)
RR1sv  =  147.0959829958**(ft^3/min)
```

### (5.2) (Case 2) Dewar Vacuum Vessel Failure

This failure will cause a loss of vacuum and a high heat load for the dewar. The dewar relief valve will vent argon as a consequence. The release rate RRv is from the dewar main relief; see section 3.10.

```
RR2  =  RRdewr+RRheater      (case 2 release rate)
RR2  =  12.0279142587**(ft^3/min)
```

### (5.3) Case 3, Piping Component Failure

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

The release rate RRpipe ; see section 3.2.

```
RR3  =  RRdewr+RRheater      (case 3 release rate)
RR3  =  12.0279142587**(ft^3/min)
```

### (5.4) Case 4, LAr Dewar Top Flange Leak

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4. The release rate RRpipe ; see section 5.2.

```
RR4  =  RRdewr+RRheater      (case 4 release rate)
RR4  =  12.0279142587**(ft^3/min)
```

## (5.5) Case 5, Premature Open Relief Valves

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4. The release rate RRpipe ; see section 5.2.

```
RR5  =  RRdewr+RRheater      (case 5 release rate)
RR5  =  12.0279142587**(ft^3/min)
```

## (5.6) Case 6, Major Operational Problems

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4. The release rate RRpipe ; see section 5.2.

```
RR6  =  RRdewr+RRheater      (case 6 release rate)
RR6  =  12.0279142587**(ft^3/min)
```

////////////

# (6.0) OPTION 1. Bathtub Mixing System , No Surface Vent, Two Mixing Fans, UPS

In this option, there is an open topped container, or as it will be called here a bathtub, below the liquid argon dewar. The bathtub would be probably be made of sheet-metal with a solid bottom. wide and long enough to catch argon, especially liquid or cold vapor falling from the cryogenic system. There will be a mixing system that would have two fans that draw air from the ceiling of the Minos Hall and discharge it through a duct into the lowest point of the bathtub mixing with any spilled argon. Only one mixing fan is needed. The fans are redundant. The fans will be on a UPS. The vent header will discharge argon onto the outlet of the mixing fans.

The mixing system ventilation probability of failure is:

```
Pffan  =  Pffan1
Pffan  =  0.93e-7
```

## (6.1) (Case 1) Dewar Internal Vessel Failure

This dewar is unusual in that in has an internal flange. The probability of an inner vessel will be the normal dewar failure rate used at Fermilab plus a gasket failure rate.

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR1)      (O2 concentration with fan)
ocr  =  0.1787532034
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.000000124**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi1  =  Pr1*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi1  =  0.2821224554e-12**(fatalities/hr)
```

## (6.2) (Case 2) Dewar Vacuum Vessel Failure

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR2)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi2  =  Pr2*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi2  =  0.198276e-11**(fatalities/hr)
```

## (6.3) Case 3, Piping Component Failure

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR3)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi3  =  Pr3*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi3  =  0.186465e-12**(fatalities/hr)
```

## (6.4) Case 4, LAr Dewar Top Flange Leak

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR4)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi4  =  Pr4*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi4  =  0.279e-13**(fatalities/hr)
```

## (6.5) Case 5, Premature Open Relief Valves

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR5)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi5  =  Pr5*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi5  =  0.279e-13**(fatalities/hr)
```

## (6.5) Case 6, Major Operational Problems

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR6)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi6  =  Pr6*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi6  =  0.0208333333e-9**(fatalities/hr)
```

## (6.6)

```
Phitotal  =  Phi1+Phi2+Phi3+Phi4+Phi5+Phi6
Phitotal  =  0.2334048078e-10**(fatalities/hr)
ODHclassification(Phitotal)  =  ODH Class 0
```

# (7.0) OPTION 2. Bathtub Mixing System With Surface Vent Header, One Mixing Fan, No UPS.

This option is the same as option 1 except there is only one mixing fan and no UPS. The Vent Header is also routed to the surface to discharge into the atmosphere. With Option 2, operational problems, by themselves, do not ever become ODH problems.

The ventilation failure rate is:

```
Pffan  =  Pffan2
Pffan  =  0.303e-3
```

## (7.1) (Case 1) Dewar Internal Vessel Failure

This dewar is unusual in that in has an internal flange. The probability of an inner vessel will be the normal dewar failure rate used at Fermilab plus a gasket failure rate.

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR1sv)      (O2 concentration with fan)
ocr  =  0.1830709924
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi1  =  Pr1*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi1  =  0.3939e-9**(fatalities/hr)
```

## (7.2) (Case 2) Dewar Vacuum Vessel Failure

```
Phi2  =  0**(fatalities/hr)
```

## (7.3) Case 3, Piping Component Failure

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR3)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi3  =  Pr3*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi3  =  0.607515e-9**(fatalities/hr)
```

## (7.4) Case 4, LAr Dewar Top Flange Leak

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR4)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi4  =  Pr4*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi4  =  0.909e-10**(fatalities/hr)
```

### (7.5) Case 5, Premature Open Relief Valves

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
Phi5  =  0**(fatalities/hr)
```

### (7.6) Case 6, Major Operational Problems

```
Phi6  =  0**(fatalities/hr)
```

### (7.7)

```
Phitotal  =  Phi1+Phi2+Phi3+Phi4+Phi5+Phi6
Phitotal  =  0.1092315e-8**(fatalities/hr)
ODHclassification(Phitotal)  =  ODH Class 0
```

# (8.0) OPTION 3. Bathtub Mixing System , No Surface Vent, One Mixing Fans, No UPS

Option 3 is the same as 0ption 1 except there is only one mixing fan and no UPS. The reliability of the mixing system is much less than with option 1.

The ventilation failure rate is:

```
Pffan  =  Pffan2
Pffan  =  0.303e-3
```

### (8.1) (Case 1) Dewar Internal Vessel Failure

This dewar is unusual in that in has an internal flange. The probability of an inner vessel will be the normal dewar failure rate used at Fermilab plus a gasket failure rate.

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR1)      (O2 concentration with fan)
ocr  =  0.1787532034
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.000000124**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi1  =  Pr1*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi1  =  0.3940611736e-9**(fatalities/hr)
```

### (8.2) (Case 2) Dewar Vacuum Vessel Failure

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR2)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi2  =  Pr2*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi2  =  0.645996e-8**(fatalities/hr)
```

### (8.3) Case 3, Piping Component Failure

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR3)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi3  =  Pr3*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi3  =  0.607515e-9**(fatalities/hr)
```

### (8.4) Case 4, LAr Dewar Top Flange Leak

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR4)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi4  =  Pr4*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi4  =  0.909e-10**(fatalities/hr)
```

### (8.5) Case 5, Premature Open Relief Valves

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR5)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi5  =  Pr5*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi5  =  0.909e-10**(fatalities/hr)
```

### (8.6) Case 6, Major Operational Problems

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR6)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi6  =  Pr6*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi6  =  0.067876344e-6**(fatalities/hr)
```

### (8.7)

```
Phitotal  =  Phi1+Phi2+Phi3+Phi4+Phi5+Phi6
Phitotal  =  0.7551968025e-7**(fatalities/hr)
ODHclassification(Phitotal)  =  ODH Class 0
```

# (9.0) Option 1 With High Operation Problem Rate

Increase the probability of a major operational problem by a factor of 10. It changes from once every 6 months to a little more than once every two weeks. Otherwise this is the same as Section 6.0.

```
Pr6   =  Pr6*10
Pr6   =  0.0022401433**(1/hr)
```

The ventilation failure rate is

```
Pffan   =  Pffan1
Pffan   =  0.93e-7
```

## (9.1) (Case 1) Dewar Internal Vessel Failure

```
ocr   =  0.21*Qmixfan/(Qmixfan+RR1)      (O2 concentration with fan)
ocr   =  0.1787532034
FFfan   =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan   =  0.000000124**fatalities
FFnofan   =  1.0**fatalities      (fatality factor with no fan)
Phi1   =  Pr1*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi1   =  0.2821224554e-12**(fatalities/hr)
```

## (9.2) (Case 2) Dewar Vacuum Vessel Failure

```
ocr   =  0.21*Qmixfan/(Qmixfan+RR2)      (O2 concentration with fan)
ocr   =  0.2075041577
FFfan   =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan   =  0.0**fatalities
FFnofan   =  1.0**fatalities      (fatality factor with no fan)
Phi2   =  Pr2*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi2   =  0.198276e-11**(fatalities/hr)
```

## (9.3) Case 3, Piping Component Failure

```
ocr   =  0.21*Qmixfan/(Qmixfan+RR3)      (O2 concentration with fan)
ocr   =  0.2075041577
FFfan   =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan   =  0.0**fatalities
FFnofan   =  1.0**fatalities      (fatality factor with no fan)
Phi3   =  Pr3*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi3   =  0.186465e-12**(fatalities/hr)
```

## (9.4) Case 4, LAr Dewar Top Flange Leak

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr   =  0.21*Qmixfan/(Qmixfan+RR4)      (O2 concentration with fan)
ocr   =  0.2075041577
FFfan   =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan   =  0.0**fatalities
FFnofan   =  1.0**fatalities      (fatality factor with no fan)
Phi4   =  Pr4*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi4   =  0.279e-13**(fatalities/hr)
```

## (9.5) Case 5, Premature Open Relief Valves

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr   =  0.21*Qmixfan/(Qmixfan+RR5)      (O2 concentration with fan)
ocr   =  0.2075041577
```

```
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi5  =  Pr5*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi5  =  0.279e-13**(fatalities/hr)
```

### (9.6) Case 6, Major Operational Problems

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR6)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi6  =  Pr6*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi6  =  0.2083333333e-9**(fatalities/hr)
```

### (9.7)

```
Phitotal  =  Phi1+Phi2+Phi3+Phi4+Phi5+Phi6
Phitotal  =  0.2108404807e-9**(fatalities/hr)
ODHclassification(Phitotal)  =  ODH Class 0
```

## (10.0) Option 3 With High Operation Problem Rate

Increase the probability of a major operational problem by a factor of 10. It changes from once every 6 months to a little more than once every two weeks. Otherwise calculations are the same as Section 8.0.

```
Pr6  =  Pr6*10
Pr6  =  0.0224014337**(1/hr)
```

The ventilation rate is

```
Pffan  =  Pffan2
Pffan  =  0.303e-3
```

### (10.1) (Case 1) Dewar Internal Vessel Failure

This dewar is unusual in that in has an internal flange. The probability of an inner vessel will be the normal dewar failure rate used at Fermilab plus a gasket failure rate.

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR1)      (O2 concentration with fan)
ocr  =  0.1787532034
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.000000124**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi1  =  Pr1*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi1  =  0.3940611736e-9**(fatalities/hr)
```

### (10.2) (Case 2) Dewar Vacuum Vessel Failure

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR2)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
```

```
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi2  =  Pr2*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi2  =  0.645996e-8**(fatalities/hr)
```

## (10.3) Case 3, Piping Component Failure

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR3)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi3  =  Pr3*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi3  =  0.607515e-9**(fatalities/hr)
```

## (10.4) Case 4, LAr Dewar Top Flange Leak

This consist of failures of piping components such as argon valves. Pfpipe , section 4.4

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR4)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi4  =  Pr4*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi4  =  0.909e-10**(fatalities/hr)
```

## (10.5) Case 5, Premature Open Relief Valves

This consist of failures of piping compoents such as argon valves. Pfpipe , section 4.4

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR5)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi5  =  Pr5*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi5  =  0.909e-10**(fatalities/hr)
```

## (10.6) Case 6, Major Operational Problems

```
ocr  =  0.21*Qmixfan/(Qmixfan+RR6)      (O2 concentration with fan)
ocr  =  0.2075041577
FFfan  =  FatalityFactor(ocr)      (fatality rate with fan)
FFfan  =  0.0**fatalities
FFnofan  =  1.0**fatalities      (fatality factor with no fan)
Phi6  =  Pr6*((1-Pffan)*FFfan+Pffan*FFnofan)
Phi6  =  0.6787634408e-5**(fatalities/hr)
```

## (10.7)

```
Phitotal  =  Phi1+Phi2+Phi3+Phi4+Phi5+Phi6
Phitotal  =  0.6795277744e-5**(fatalities/hr)
ODHclassification(Phitotal)  =  ODH Class 1
```